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SIDEREAL-DAY VARIATION IN SPONTANEOUS ACTIVITY OF THE MOUSE, *MUS MUSCULUS* [1]

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A body of data has been developed to indicate that the spontaneous motor activity of a number of small mammals is not random in its variation but tends to possess recurring patterns. These patterns include solar-day, lunar-day, synodic-monthly, and annual periodicities (Boyer, 1970; Brown, F. A., 1965; Brown and Park, 1967; Brown, Shriner, and Ralph, 1956; Brown, J. A., 1973; DeCoursey, 1959; Johnson, 1939; Kavanau, 1962, 1969; Stutz, 1970, 1972, 1973, 1974; Terracini and Brown, 1961, 1962).

In a study of the spontaneous motor activity of the mouse, *Mus musculus*, a rhythm of even another periodicity has been observed (Brown, J. A., 1973). This is the sidereal-day pattern of mean activity. Due to the great distance of the stars from the earth, rotation relative to them constitutes the earth's actual period of the rotation. This is the sidereal-day and has a period of 23 hours 56 minutes. The sidereal-day is close to four minutes shorter than the solar-day cycle (24 hours). The sideral-day, therefore, as a consequence of the annual orbital passage of the rotating earth around the sun gains on the solar-day two hours each month or just 24 hours in a year. A rhythm of this period has also been observed in the pattern of oxygen consumption in potatoes (Brown, F. A., 1958).

This paper will present the characteristics of this observed sidereal-day pattern and will discuss the possible relation of this pattern to the timing of annual rhythms and nocturnal navigation.

Materials and Methods

Twelve adult male Swiss white mice, *Mus musculus*, three months old at the beginning of the experiment were used. Each mouse was maintained in the experiment until sickness or death resulted. At this time another mouse was substituted as the experiment continued. The experiment ran continuously from June 1, 1965 to May 31, 1966.

Each mouse was housed in a tilting-cage actograph similar to the type used by Terracini and Brown (1962). The rocking cage movements effected by the movement of the animal were transformed by the recording system, an Esterline Angus events recorder, into one lateral movement of a recording pen for each excursion of the mouse to an opposite side of the "track". The rate of movement of the paper was 0.75 inches an hour or 18 inches a day. The movements of the mouse from one side of the cage to the other involved, obviously, running or walking activity.

[1] This research was based upon a portion of a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree in biological sciences at Northwestern University, Evanston, Illinois, in June 1973.

The mice were subjected to the natural variation in the duration of illumination. The temperature of the room was maintained at approximately 22° C, thermostatically controlled throughout the colder months of the year, but rising during warmer days of summer to 25° C or higher. Water and food were constantly available to the mice. The times of renewing water and food were varied randomly as were all disturbances associated with servicing the actographs and recording systems.

The data which were used were obtained from the actograph recordings and quantified in the following manner: (1) the hour by hour (all times were Central Standard) activity records for each mouse, individually, were given numerical values in terms of a scale ranging from 0 to 10. The numbers described the fractions of the hour that the animal was active. For example, 0 indicated no activity, 2 indicated 20% of the hour, and 10 was 100% of the hour. (2) These values were then tabulated to indicate the hourly numerical units of activity for each mouse for each day of the experiment. (3) The individual hourly data for all mice were then combined into monthly tables showing the combined total activity for all the mice for each hour of each day of the consecutive months. These monthly tables served as the basis for further analysis of the sidereal variational patterns of the spontaneous motor activity of the mice.

The pattern of the mean sidereal cycle can be obtained from units of a year of hourly data by simply displacing consecutive mean monthly 24-hour cycles to progessively two-hour later relationships in the day. Using data for a whole year will obviously randomize the mean solar-day and mean lunar-day and, for all practical purposes, the monthly components as well. These mean hourly values so aligned in columns of the twelve monthly rows of mean 24-hour data are essentially the hours (± 1) of the sidereal-day (see Figure 1).

Since sidereal midnight is defined as the instant at which the vernal equinox crosses the upper meridian, and sidereal noon the instant the vernal equinox crosses the lower meridian, sidereal hour 24 (0) will lie within that vertical column containing solar-day noon for March–April and solar-day midnight for September–October. Because for the originally monitored solar-day data the 12th hour represented the amount of spontaneous motor activity from 11 to 12 AM and the 13th hour represented activity from 12 AM to 1 PM, and also because of the 2-hour slide, the data were combined into 2-hour periods in the solar-day. The two-hour means can thus come close to being centered on the sidereal times of noon and midnight. While sidereal 0 and 12 reach upper transit at solar-day noon on the vernal and autumnal equinoxes, respectively, the 6th hour of the sidereal-day reaches upper transit at noon on the summer solstice about June 21. Comparably, the 18th sidereal hour reaches upper transit at noon on the winter solstice about December 22.

Results

The sidereal-day pattern obtained from the data on the spontaneous motor activity of the mice studied from June 1, 1965 through May 31, 1966 is indicated in Figure 2. The approximate hours of the sidereal-day are indicated on the abscissa. The mean hourly value for the year is 18.8. The mean hourly values, expressed as deviation from the yearly mean, range from -4.7 to $+3.8$. The

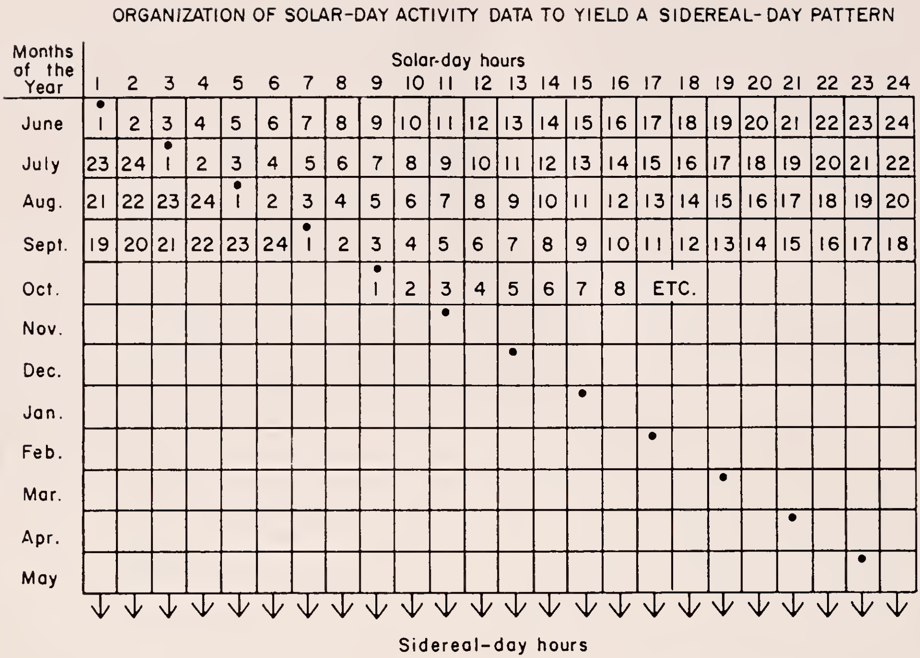

FIGURE 1. The values within the boxes indicate the hourly organization as they are shifted two hours later each month.

range of variation is 40% of the overall mean value. The gradual shift of the phase relationship of the sidereal cycle to the daily cycle of the mice is diagrammatically depicted in Figure 3.

The sidereal pattern for the mouse data comprises a unimodal variation with a maximum occurring at the midnight hour (0) of the sidereal day and a minimum at the 12th hour. There has been to date only a single search in organisms for a variation correlated with the sidereal period. A mean pattern of variation possessing this period was reported for O_2-consumption in potatoes for a two-year study (Brown, F. A., 1958). The sidereal pattern of the mouse differs from the sidereal component of O_2-consumption in potatoes observed over the period from February 1, 1956 to January 31, 1958 in being about 8 hours, or 120°, phase-advanced. In general form they appear to be moderately similar. An eight-hour lead correlation of the mouse cycle on the potato yielded $r = +0.86 \pm 0.08$. The phase difference between the mouse and the potato cycles was not the result of a difference in the years at which the investigations were conducted because further continuation of the potato study through 1967 (including the interval of the mice study) discloses no difference in phase or form of the cycle as compared with the earlier sidereal analysis. Results obtained from an 11-year sidereal analysis for the potato (Figure 4) were obtained through personal communication with Dr. F. A. Brown, Jr., Northwestern University (see also Brown, F. A., 1973).

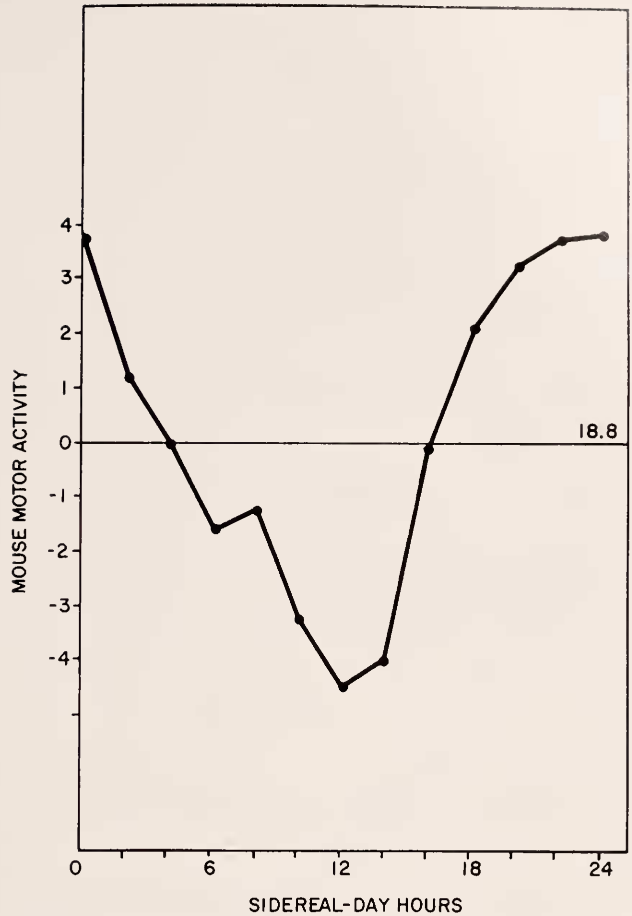

FIGURE 2. Values are two-hour averages expressed as deviation from the mean hourly sidereal-day activity, indicated on the abscissa.

DISCUSSION

The unimodal sidereal-day cycle of spontaneous mouse motor activity represents another example of a behavioral pattern synchronized with a major geophysical cycle. Other evidence of geophysically correlated periodisms in the mouse, *Mus musculus,* is reported in Boyer, 1970; Brown, J. A., 1973; Terracini and Brown, 1962; Truchan and Boyer, 1972. Variations of sidereal-day periods have been observed for the electromagentic fields of the earth. The sensitivity of organisms to weak electromagnetic fields of the intensity as found on earth has been well documented (Brown, F. A., 1971; Brown, Park, and Zeno, 1966; Lindauer and Martin, 1968; Rommel and McCleave, 1972; Wiltschko and Wiltschko, 1972; and many others). The occurrence of another geophysically correlated pattern, the sidereal-day one, seems to add more evidence to the recent studies

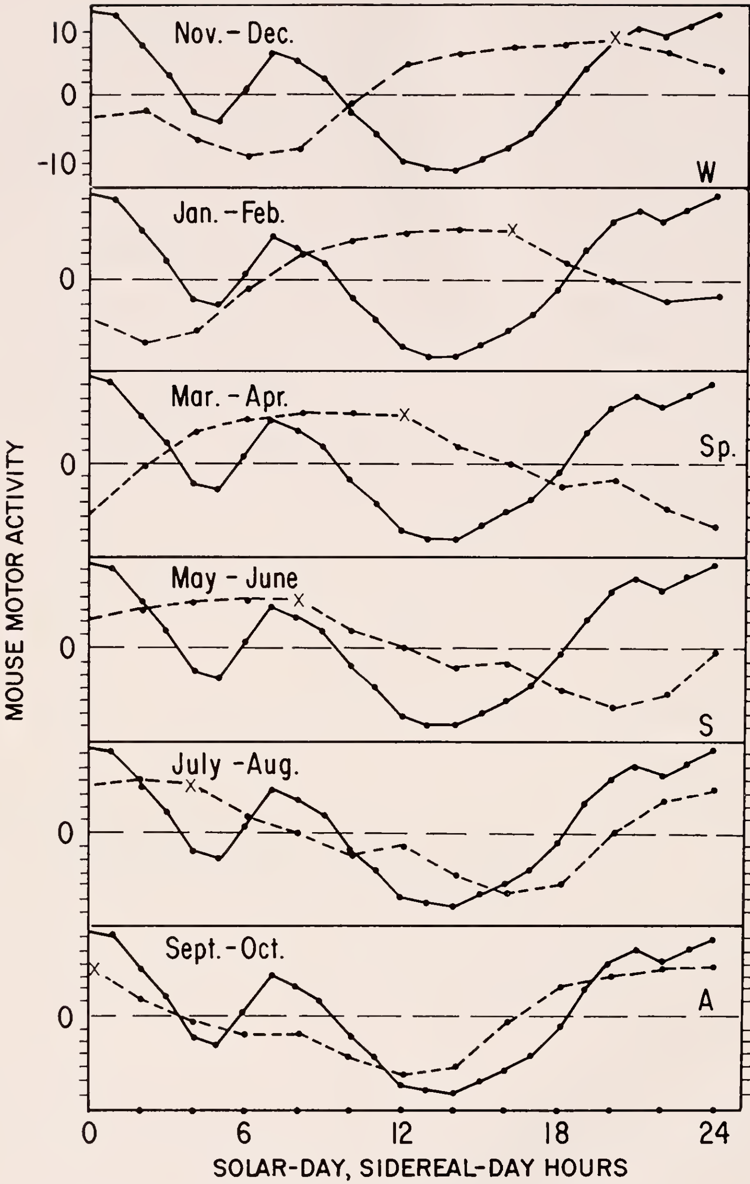

FIGURE 3. The yearly movement of the sidereal-day activity pattern across the mean solar-day activity pattern.

Mean solar-day pattern is indicated by the solid line. Sidereal-day pattern is indicated by the dashed line.

All the values are expressed as direction and deviation from a common mean indicated by the dashed line. Solar-day values are indicated on the left ordinate. Sidereal-day values are indicated on the right ordinate.

The x describes the movement of the (O) sidereal hour as it crosses the solar-day pattern during the year. W indicates the time of winter solstice; Sp.—the spring equinox, S—the summer solstice, and A—the autumnal equinox.

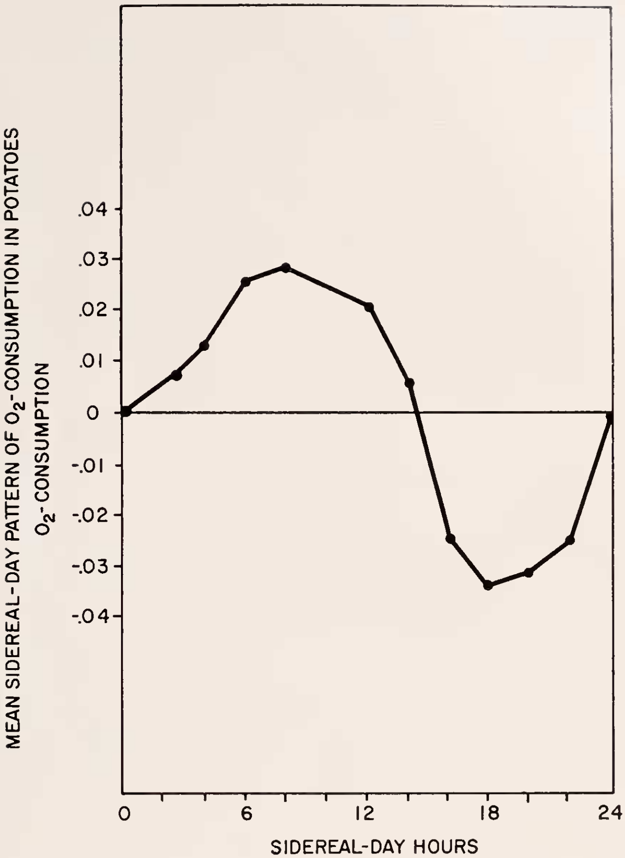

FIGURE 4. Potatoes were maintained in constant conditions of all obvious factors February 1, 1956 through January 31, 1967. Cycle range is about 1 percent of the mean rate.

that indicate these weak electromagnetic fields may be the timing mechanism for the biological clock (Brown, F. A., 1972; Brown, and Chow, 1973).

A mean annual pattern of spontaneous motor activity in the mouse, *Mus musculus,* has been observed (Brown, J. A., 1973). An annual rhythm can result from the periodic reinforcement of the solar-day cycle by the sidereal one of 23 hours and 56 minutes. The sidereal-day cycle scans across the 24 hour day in exactly one year (Figure 3). As another example of a timing mechanism that employs the changing phase-relationships between two basic geophysically related cycles to yield a third there has been observed the mean pattern of synodic-monthly frequency (29.53 days). This periodism is the result, in at least some measure, of the systematically altering phase-relationships between the 24-hour solar-day and the 24.8-hour lunar-day, with consequent periodic reinforcement of the solar-day maxima with a mean synodic-monthly frequency (29.53 days). The presence of a pattern possessing this period in the spontaneous activity pattern of the mouse has been noted previously by Boyer (1970), J. A. Brown (1973), and Terracini and Brown (1962). The existence of this periodicity in other mammals has been observed for hamsters (Brown and Park, 1967), rats (Brown, Shriner, and Ralph, 1956) and Mongolian gerbils (Stutz, 1973).

One more role that the presence of a sidereal-day pattern might play in the behavior of animals is involved with the mechanisms used by animals for nocturnal navigation. Although there seems to be little total agreement as to the mechanism that is used by birds specifically in nocturnal navigation, if the use of celestial bodies as navigational reference points is to be considered reasonable, the ability of birds to compensate for the apparent motion of the stars necessitates a biological clock with a period of the sidereal-day rhythm (Wallace, 1973). We have mounting evidence in both potatoes and mice that at least certain organisms do possess patterns of this period length. Further study to indicate such a recurring pattern in other organisms is necessary.

Summary

1. Spontaneous motor activity of twelve adult male Swiss white mice was monitored for the year June 1, 1965 through May 31, 1966, in Evanston, Illinois. The mice were maintained in natural illumination in the laboratory.

2. A mean sidereal-day activity pattern was disclosed. This comprised a unimodal variation with a maximum occurring at sidereal midnight (hour 0) and a minimum at the 12th hour. The range of the cycle was 40% of the mean. It is postulated that the sidereal variational pattern reflects biological responsiveness to the mean sidereal-day fluctuations in the geoelectromagnetic field.

3. The presence of an annual pattern of spontaneous motor activity is postulated to be the result, in at least some measure, of the systematically altering phase-relationships between the 24-hour solar-day and the 23-hour 56-minutes sidereal-day as the sidereal-day makes it passage across the solar-day to be completed exactly in one year's period.

4. The significance of a sidereal-day periodicity to nocturnally migrating organisms is postulated.

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